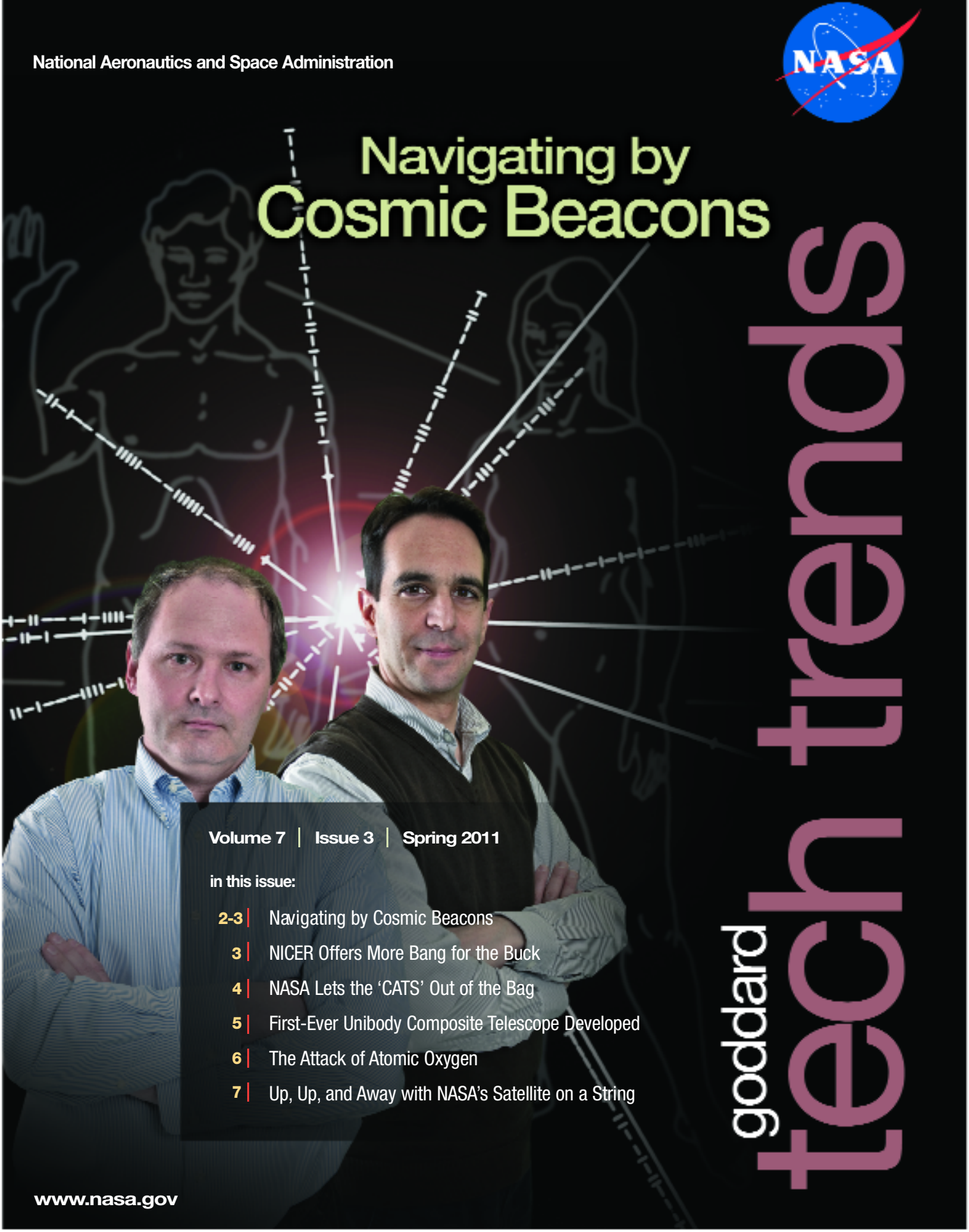
National Aeronautics and Space Administration



Navigating by Cosmic Beacons

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Navigating by Cosmic Beacons

Revolutionary Navigation and Communication Payload Receives NASA Funding

Imagine a technology that would allow space travelers to transmit gigabytes of data per second over interplanetary distances or to navigate to Mars and beyond using powerful beams of light emanating from rotating neutron stars.

The concept isn't farfetched.

In fact, Goddard astrophysicists Keith Gendreau and Zaven Arzoumanian plan to fly a multi-purpose instrument on the International Space Station to demonstrate the viability of two groundbreaking navigation and communication technologies and, from the same platform, gather scientific data revealing the physics of dense matter in neutron stars (see related story, page 3).

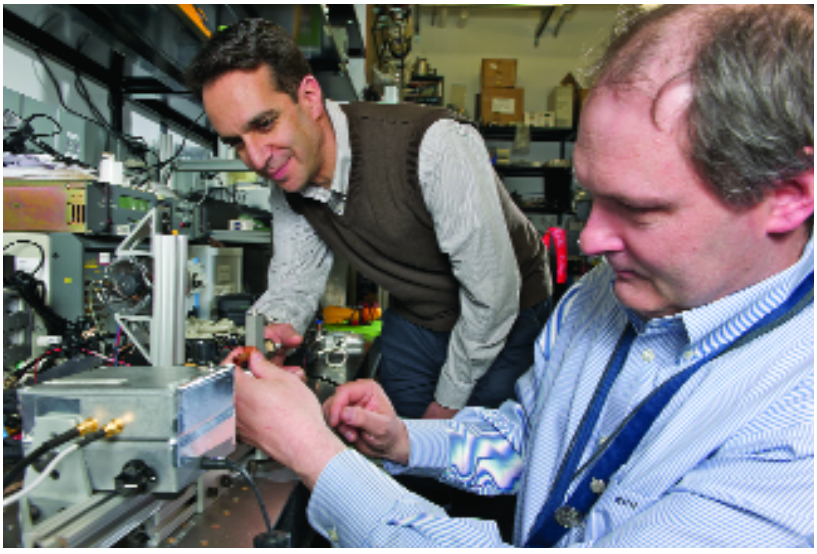

Photo Credit: Chris Gunn

Principal Investigators Keith Gendreau (seated) and Zaven Arzoumanian are fine-tuning their Modulated X-ray Source, which will play a pivotal role in the demonstration of the world's first X-ray communication system.

Selected for development by NASA's Office of the Chief Technologist, the X-ray Navigation Demonstrator (XNAV) will include 56 X-ray telescopes, silicon detectors, and a number of other advanced technologies in a package about the size of a large recycling bin. Gendreau and his team say they plan to deliver the payload to the orbiting outpost in 2015 to begin the disparate, yet related, investigations.

"It's rare that you get an opportunity to develop a cross-cutting experiment," Gendreau said. "This technology touches seemingly disjointed things: X-ray astrophysics, navigation, and new techniques to communicate over interplanetary distances. The time is right for this experiment. This is one that we can do now."

Stellar Lighthouses Show the Way

The instrument demonstration is the first step in realizing pulsar-based navigation — a concept advanced after the discovery of these unusual celestial objects in 1967, Gendreau said. Pulsars are a subgroup of neutron stars. They rotate rapidly, emitting powerful beams of light from their magnetic poles that sweep around as the star spins, much like a lighthouse. On Earth, these beams are seen as flashes of light, blinking on and off at intervals from seconds to sub-milliseconds.

Because of their predictable pulsations, "they are highly reliable celestial clocks" and can provide high-precision timing just like the atomic clock signals supplied through the 26-satellite, military-operated Global Positioning System (GPS), Arzoumanian said. Although GPS offers highly reliable location and time information to anyone with a GPS receiver, it is geared to Earth-based applications. As a result, GPS signals weaken the farther one travels out into the Solar System. "Pulsars, on the other hand, are accessible in virtually every conceivable flight regime, from low-Earth orbit to interplanetary to deepest space," Gendreau said.

To demonstrate the viability of pulsar-based navigation, Gendreau and his team, including the Massachusetts

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Photo Credit: Chris Gunn

About the Cover:

Goddard astrophysicists Keith Gendreau and Zaven Arzoumanian have proposed a multi-purpose instrument to demonstrate a potentially game-changing navigation technology that uses pulsars as a time and navigation standard. The instrument would realize the concept of a pulsar-based map, whose pictorial elements are shown in the background. First used on a plaque attached to NASA's Pioneer 10 spacecraft, the map's radiating lines represent the positions and pulse periods of 14 pulsars, encoding the Sun's location in the Milky Way.

Cosmic Beacons... *Continued from page 2*

Institute of Technology, the Naval Research Laboratory, the National Institute of Standards and Technology, and others, will develop the XNAV experiment as a payload on the International Space Station's Express Logistics Carrier, an unpressurized payload platform. The instrument will use its 56 telescopes to detect X-ray photons in these powerful beams of pulsated light to estimate their arrival times. With these measurements, the system will stitch together an on-board navigational solution using specially developed algorithms.

If an interplanetary mission were equipped with such a navigational device, it would be able to calculate its location autonomously, independent of NASA's Deep Space Network (DSN), Gendreau said. DSN, considered the most sensitive telecommunications system in the world, allows NASA to continuously observe and communicate with interplanetary spacecraft. However, like GPS, the system is Earth-centric. Navigational solutions also degrade the farther one travels out into the Solar System. Furthermore, missions must share time on the network, Gendreau said.

"To better explore new worlds beyond low-Earth orbit, we will need additional navigational solutions. XNAV enables deep-space missions that are not feasible with Earth-based tracking," he added.

X-Ray Communication

The multi-purpose payload also will enable a demonstration of the world's first X-ray communication system. This test will feature Goddard's Modulated X-ray Source (MXS), which turns on and off many times per second to encode digital bits for transmitting data. Since developing the MXS with Goddard and Defense Department R&D funds, Gendreau has demonstrated 500 kilobyte-per-second data rates using the device (*Tech Trends*, Summer 2007, Page 3). The goal is to one day transmit gigabytes of data per second with minimal power.

His plan is to fly the MXS on a supply spacecraft. As the craft approaches the Space Station, MXS will transmit data via the modulated X-rays, which the XNAV hardware would then receive.

Should the first space-based demonstration succeed, Gendreau said it would be laying the foundation for a more powerful way to transmit data across vast distances. "This is a baby step toward interplanetary X-ray communication," Gendreau said. "We understand these technologies," Arzoumanian added. "We understand how to build the payload. We need to show what is feasible. This experiment will tell us what we can do." ◆

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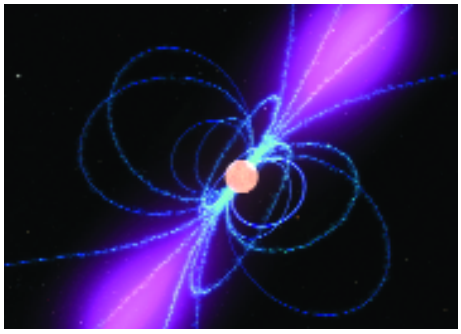
More Bang for the Buck

Talk about getting more bang for the buck. The same payload selected to help demonstrate two potentially "game-changing" technologies on the International Space Station also would allow astrophysicists Keith Gendreau and Zaven Arzoumanian, together with an expert science team, to study the nature of matter in neutron stars.



Clouds of charged particles move along the pulsar's magnetic field lines (blue) and create a lighthouse-like beam of gamma rays (purple) in this illustration.

Responding to a NASA solicitation for an Explorer-class mission, the team has proposed the Neutron Star Interior Composition Explorer (NICER). The mission would share the same payload now being developed with NASA technology funds (see related story, page 2).

"The hardware needed for the X-ray Navigation Demonstrator is identical to that needed for NICER," Gendreau said. "In fact, they share the same targets and operational concept. The differences are on the back end in terms of how the data will be used."

The principal scientific objective is learning more about the interior composition of neutron stars, the remnants of massive stars that, after exhausting their nuclear fuel, exploded and collapsed into super-dense spheres about the size of New York City. Just one teaspoonful of their material would weigh a billion tons on Earth. "NICER will uncover the nature and probe the physics of ultra-dense matter in these stars," Gendreau added.

Although neutron stars emit radiation across the spectrum, observing in the X-ray band offers the greatest insights into the objects' thermal, magnetic, and rotational characteristics. As a result, the experiment package will carry 56 X-ray telescopes, silicon detectors, and other advanced technologies."NICER meets critical science objectives and is a stepping stone for technology applications that meet a variety of NASA needs," Gendreau said. "It's rare that you get an opportunity to do a crosscutting experiment like this." ◆

NASA Lets the 'CATS' Out of the Bag

New Instrument to Observe Clouds and Aerosols from the International Space Station

A Goddard scientist, who has built and delivered five different aircraft-borne instruments in just 12 years, has been selected to build yet another — this time, a dual-frequency lidar that will fly a little higher in altitude on the International Space Station's Japanese Experiment Module (JEM).

In March, NASA announced it had selected the Cloud-Aerosol-Transport System (CATS) as one of the first U.S.-provided "hitchhiker-type" instruments to be installed on JEM's Exposed Facility, an attached payload carrier. The instrument, which will showcase data-gathering techniques important to future missions, will be completed and delivered in two years.

"They looked at us and acknowledged we had built five instruments in a relatively short period of time and that we had a track record for developing high-altitude, small, autonomously operated instruments on time and on budget," said scientist Matt McGill, who is managing the instrument's development with his colleague, Stan Scott. "It's a perfect payload for Space Station and it's a good opportunity for us."

From its Earth-observing perch, CATS will provide long-term observations of clouds and aerosols — tiny particles suspended in the atmosphere — to study their influence on atmospheric circulation and precipitation. Of particular interest to Earth scientists is the ability to track in near real time aerosol plumes such as those created in sandstorms or volcanic eruptions. "The space station orbit is ideal for tracking plumes and studying their daily effects," McGill said.

Volcanoes such as those shown here produce ash and prodigious amounts of sulfur dioxide, which interact with air to produce sulfate aerosols. The Goddard-developed CATS instrument will monitor clouds and aerosols from its perch onboard the International Space Station.

It also will test an experimental channel that will directly measure microphysical properties of clouds and aerosols — a capability identified for the proposed Aerosol-Cloud-Ecosystems (ACE) mission recommended by the National Research Council's Decadal Survey for Earth Science.

Data Continuity

Just as important, CATS will ensure the continuity of cloud and aerosol data. Currently, CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite), a joint mission with the French space agency, CNES, is providing that data. However, "the U.S. will have no aerosol or cloud profiling capability from space after CALIPSO ends," McGill said. ACE, should NASA decide to fund the mission, isn't expected to fly until 2020. "Our instrument will help fill the data gap," McGill said.

McGill said CATS will be a hybrid instrument combining capabilities available on a similarly named instrument that McGill developed specifically for NASA's ER-2 aircraft. That instrument, affectionately known as "airplane CATS," was tested for the first time in April. It also incorporates the capabilities of McGill's Cloud Physics Lidar, which he and his team demonstrated on the inaugural flight of NASA's unmanned Global Hawk aircraft last year (*Tech Trends*, Summer 2010, Page 5). Both were developed with Goddard and Earth Science Technology Office R&D funding.

"This is the perfect success story," McGill said. "These investments led to this award." ◆

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First-Ever Unibody Composite Telescope Developed

Team Leverages Knowledge from Composite Crew Module Challenge

When 30 NASA engineers set out to build and test an experimental crew module made entirely of lightweight composite materials a few years ago, little did they know that their work ultimately would benefit scientists developing a one-of-a-kind instrument designed to profile tropospheric winds — a key measurement for improving weather prediction.

But that's precisely what has happened.

A Goddard team, led by Principal Investigator Cathy Marx and Earth scientist Bruce Gentry, has tapped the expertise of Goddard materials engineer Dan Polis to build what is believed to be the first complex, contoured unibody structure built of a lightweight carbon-fiber epoxy material. Unibody or monocoque construction is a technique where an object's exterior supports its structural load rather than an internal frame or truss.

Goddard engineers are leveraging lessons learned building the Composite Crew Module pictured here to create the first unibody design for a telescope. The structure will be used for an Earth science instrument.

Polis was one of 30 NASA engineers who participated in an 18-month tiger team challenge to design, build, and test the 12-foot-wide Composite Crew Module — an effort started for the sole purpose of giving engineers in-house experience designing and constructing complex spacecraft with composite materials (*Tech Trends*, Spring 2007, Page 7). The team completed the crew module in 2009.

In particular, Polis is leveraging what he learned to help advance Goddard's Tropospheric Wind Lidar Technology Experiment (TWiLiTE), the first and only molecular Doppler lidar system to profile winds. Designed to operate autonomously on high-altitude aircraft, the advanced instrument is slated to fly on the NASA Global Hawk in 2013 as part of NASA's four-year Hurricane and Severe Storm Sentinel (HS3) mission aimed at discovering why hurricanes intensify (*Tech Trends*, Summer 2010, Page 4).

TWiLiTE Design

TWiLiTE gathers wind data by transmitting ultraviolet pulses through the atmosphere. A small fraction of the laser signal scatters off molecules in the atmosphere and returns to the instrument where it is collected by the telescope. An onboard Doppler receiver analyzes the return signals to determine wind direction and speed. Although the molecular system is not as precise as other measurement techniques, the advantage of such a system is that molecules are omnipresent and signals can be measured anywhere, including in clear air.

Though unique, TWiLiTE is undergoing a metamorphosis to make it more capable and better suited as a space-based instrument for the 3-D Tropospheric Winds mission recommended by the National Research Council's Decadal Survey for Earth Science, Gentry said. "The technology we're putting into the system extends the instrument beyond the airborne system to space-based use," he said.

Specifically, he, Marx, and Goddard engineers Pat Jordan, Ed Faust, and Pete Dogoda are using Goddard and NASA Earth Science Technology Office R&D funds to add an infrared channel to measure signals scattered off tiny particles or aerosols in the atmosphere if any are present.

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Attack of Atomic Oxygen: Molecule Slithers into the Spotlight

Decades ago, NASA engineers figured out how to prevent a highly pervasive molecule in low-Earth orbit from destroying materials commonly used on the external surfaces of spacecraft and components. Imagine their surprise when scientists discovered signs of degradation deep within the Hubble Space Telescope.

"We thought we understood the problem," said Nancy Carosso, chief engineer of Goddard's Contamination and Coatings Engineering Branch. She and her colleagues now have found evidence that the internal surfaces of Hubble's Corrective Optics Space Telescope Axial Replacement (COSTAR) instrument had degraded during its many years in space. COSTAR was returned home after astronauts replaced it in 2009 with the Cosmic Origins Spectrograph (COS).

The culprit? Based on ground tests and other sleuthing, the degradation likely was caused by low-velocity atomic oxygen molecules finding their way inside the instrument and ricocheting off the surfaces, Carosso said.

Scientists discovered the COSTAR problem by accident during an investigation into why COS was showing signs of possible degradation. Although COS's science capabilities are in no immediate danger, the sensitivity of the instrument's windowless cesium-iodide detectors appears to be degrading five percent or more per year.

As part of the investigation, which is still continuing, engineers with the Contamination and Coatings Engineering Branch asked the Smithsonian Institution — now COSTAR's official guardian — for permission to obtain a sample of COSTAR's ribbon cable. Though engineers couldn't see any visible damage to the cable, a look under the microscope and chemical analysis told a different story. The sample was pitted — a telltale signature of exposure to atomic oxygen.

Even if atomic oxygen isn't causing COS's degradation, the presence of atomic oxygen inside Hubble is a warning to other instrument designers, said David Hughes, a senior engineer who examined COSTAR. Developers of the Air Force's Special Sensor Ultraviolet Limb Imager, for example, also have noticed degradation of their instrument's cesium-iodide detector. "We might be the first people to have thought that atomic oxygen is to blame, but we're not the first to have experienced the molecule's ill effects," Hughes said.

This isn't the first time engineers have waged war against the corrosive effects of atomic oxygen.

Engineers first became aware of its harmful effects in the 1980s. Materials exposed to the molecule while the Space Shuttle orbited the Earth at high velocities — particularly those enshrouding payloads stashed in the opened cargo bay — showed obvious signs of serious wear. The high-velocity impacts etched or "frosted" Kapton, a commonly

Photo Credit: Chris Gunn

Engineers Nancy Carosso and David Hughes are pictured here with spacecraft components that had been damaged due to exposure to atomic oxygen.

used film used as a thermal insulator on instruments. Components made of silver Teflon returned home ripped. Some coatings and materials even oxidized to the point where they had disappeared.

To understand what had caused the damage, NASA engineers carried out flight experiments on various Space Shuttle missions and the International Space Station. They developed predictive models. "We learned from the Shuttle experience. We learned what materials to use and what materials not to use on the outer surfaces of spacecraft and instruments operating in low-Earth orbit," Carosso said. "We thought we had the problem licked."

Based on her team's analysis, however, that doesn't appear to be the case.

To avoid future degradation of instrument components, Carosso and Hughes have proposed a multi-faceted research effort to find out just how the molecule slithers its way into instruments. They also plan to establish a laboratory where they would test different detector materials to determine which are immune to degradation.

The information is critical to instrument designers, Hughes added. Atomic oxygen, already plentiful in low-Earth orbit, increases in relation to solar activity. Unfortunately for potentially vulnerable instruments, the Sun is entering its solar maximum, the cyclical period of greatest solar activity.

"We never suspected that atomic oxygen could get inside a spacecraft," Carosso explained. "We thought we understood the problem for high-energy atomic oxygen ruining external surfaces; now we see evidence of internal surfaces being degraded. So now, here we go again," Carosso said. "We're the ones building hardware. We need to thoroughly understand what's going on here." ◆

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Up, Up, and Away with NASA's Satellite on a String

Wallops Team Demonstrates 14-Million-Cubic-Foot Pressure Balloon

With the successful demonstration of a football field-sized super-pressure balloon in Antarctica earlier this year, engineers say they have passed a major milestone in their quest to provide scientists with a "satellite on a string" — a platform that will provide long-duration, low-cost access to near space. Work now begins on an even larger vehicle capable of flying one-ton scientific payloads.

In January, engineers successfully launched a 14-million-cubic-foot super-pressure balloon from the Ross Ice Shelf in Antarctica. Twenty-two days later, after making a full orbit at a consistent altitude of 111,000 feet, the pumpkin-shaped balloon was brought down to ensure recoverability of its payload.

In January, engineers successfully launched a 14-million-cubic-foot super-pressure balloon from the Ross Ice Shelf in Antarctica.

The flight validated changes engineers made to scale up from a 7-million-cubic-foot design tested in late 2008 to its current size capable of carrying 4,000 pounds of suspended weight. It also laid the groundwork for the ultimate balloon — a 26-million-cubic-foot version, which would be even larger in diameter than a football field and capable of staying aloft for up to 100 days. The team plans to demonstrate it in 2013.

"We're on the verge of supporting science for significantly longer durations," said David Pierce, chief of the NASA Balloon Program managed by the Suborbital and Special Orbital Projects Directorate at the Wallops Flight Facility. "It's exciting to see this engineering development becoming an operational reality."

Rivals Satellites

Wallops began developing these pressurized floating behemoths nearly a decade ago as a viable alternative to orbiting spacecraft and to extend the capabilities of the Balloon Program's current offerings. Made of a co-extruded polyethylene film no thicker than ordinary plastic food wrap, super-pressure balloons are pressurized just enough to maintain their volume so that cooler nighttime temperatures do not affect the float altitude. As a result, they are able to maintain a consistent altitude above 99 percent of the atmosphere for weeks at a time, making them competitive with satellites for investigations that can be done in near space. An added advantage is that scientists can retrieve, refurbish, improve, and reuse their payloads during subsequent balloon missions.

Zero-pressure balloons, on the other hand, are not pressurized and expand and contract with changes in temperature. That means these balloons — NASA's current workhorses — must vent gas during the daytime and drop ballast, usually sand, at night to maintain an operable platform Eventually, one or the other runs out and the mission ends, usually within a few days if flying at mid latitudes.

Engineers have long known the advantages of pressurized balloons. The problem is they are difficult to build. "We've never done anything as complicated as these balloons," said Chief Designer Rodger Farley. In addition to determining the most effective shape, the Wallops team had to make sure the polyethylene material could withstand the pressure and not degrade due to exposure to ultraviolet radiation. This required intensive analysis and testing. "We're trying to do something that hasn't been done before," added Test Manager Henry Cathey.

The team intends to execute another test flight in December 2011, and ultimately declare the 14-million-cubic-foot balloon fully operational by 2013, said Balloon Program Chief Technologist Debora Fairbrother.

Work Continues

Meanwhile, work continues on the largest version of the super-pressure balloon fleet, the 26-million-cubic-foot colossus that can carry one-ton scientific payloads to above 100,000 feet, which is up to four times higher than where planes fly. Fairbrother believes the team will be ready for the first test flight of this balloon in 2012.

Their availability won't come too soon for the scientific community, said John Mitchell, deputy project scientist for the Balloon Program. When development is complete, scientists will have another platform from which to carry out their research from Earth and even in missions to other planets. "That's the big thing," Mitchell said. "They give us another tool."

"It's encouraging to us," Cathey said. "We have a product that scientists are anxious to use." ◆

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Composite... Continued from page 5

With both channels, TWiLiTE will be able to profile winds under any atmospheric conditions.

The team also is reconfiguring the telescope optics to provide multiple viewing angles needed for profiling three-dimensional winds. Instead of installing just one telescope, which is typical of most lidar systems, the new-and-improved TWiLiTE will be equipped with four telescopes positioned 45 degrees apart off nadir on a structure that looks something like a space capsule. Both the ultraviolet and infrared laser beams will be combined into a common optical path and a small rotating mirror will select one of the four telescopes from which to transmit the beams. On their return, the signals will be separated and sent to either the aerosol or molecular receiver.

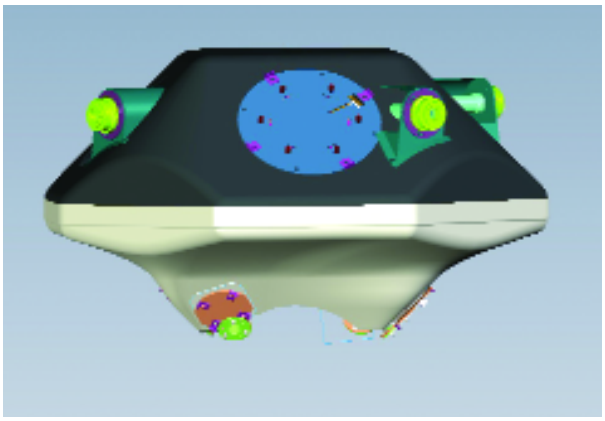
Building Unusual Telescope Housing

How then to build this unusual housing for a telescope system? The team originally planned to build the structure from machined aluminum parts, but decided to use composite materials because of their relative stiffness and immunity to distortions caused by changes in temperature. "We knew what we wanted to do. Composites offered the perfect solution, but we didn't have the tools to develop the structure," Jordan said. Starting from scratch was not an option, either, particularly for a complex technology-development project with a limited budget and tight schedule.

Enter Dan Polis and the Goddard Composite Materials Engineering Technology team. "What we're doing is taking lessons learned in aircraft design to develop a three-foot-wide telescope," Polis said.

Although Goddard has a rich tradition creating custom composite components for a variety of scientific instruments, it has never built anything quite like this for a science application, Polis said. "This is the first unibody design for a telescope."

The structure, which features four portals from which the telescopes will point, will be made of only two pieces of carbon-fiber epoxy formed over a foam mold and cured under relatively low pressures, Polis said.



This is a drawing of the composite telescope structure being developed for Goddard's TWiLiTE instrument.

Other than for the two composite shells that the team will bond together, the structure will have no parts that must be fitted together with clips, plates, or fittings. Nor will these parts be cured in an autoclave, a type of pressurized oven, under high temperatures and pressure. As a result of this "out-of-autoclave" process, the structure is expected to cost a quarter of the price and take half the time to manufacture compared with more traditional fabrication techniques. The team expects to deliver the structure this summer in plenty of time for Gentry to prepare the advanced instrument for its flight on the HS3 mission in 2013.

"It's very satisfying to have the fruits of our labor — particularly in designing complex, three-dimensional composite structures — transition so beautifully into future ventures like TWiLiTE," said Jeff Stewart, who served as the deputy project manager on the multi-center Composite Crew Module tiger team. "This is a unique application of what we learned over that months-long effort." ◆

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